LINAC SHIELDING

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1. General Introduction

The neutron source and neutron transport through different types of shields was calculated for our linac enclosure by Mr. Keran O'Brien of the U.S. A.E.C. N.Y.O.O., Health and Safety Laboratory.

The assumptions made in these calculations are listed below. Naturally, some simplified geometry was adopted.

2. Neutron Source

2.1 Proton Loss. Infinite and uniform line source of monochromatic protons on copper.

2.2 Protons that interacted, interacted at their incident energy (this will over estimate somewhat the neutron flux and its hardness). Cascade protons are neglected (this may underestimate the neutron source by not more than 10-15%). Evaporation neutrons and protons are neglected at the source if $E_p \gg 150$ MeV.

2.3 The thickness of the linac in a direction perpendicular to the beam is to be included in the shielding thickness.

2.4 The total current loss in the linac is 1% of the 200 MeV current.

2.5 The significant current loss occurs from the end of the first tank (E_p - 10 MeV) to the end of the last tank (E_p = 200 MeV). Then,

$$L = 1.3814 \times 10^4 \text{ cm}$$

proton current loss $= 10^{-2} \times 5.2 \times 10^{14}$ p/sec

$$= 5.2 \times 10^{12} \text{ p/sec}$$

finally

$$(di/dL) = 3.76 \times 10^{8} \text{ p sec}^{-1} \text{ cm}^{-1}$$

3. Type of Calculation

This was a multigroup, one region neutron transport calculation. The details are given in HASL - Technical Memorandum 67-9, written by K. O'Brien and J. McLaughlin.

The numerical work was mostly done at N. Y. U. 's CDC-6600.

4. Neutron Cross-Sections

The production of neutrons by incident protons was taken from ORNL-4046.

The non-elastic cross-sections for p's and n's for $E \geqslant 25$ MeV are also taken from ORNL-4046.

The neutron elastic cross-sections are taken from BNL-325, for all energies.

The neutron non-elastic cross-sections for $E \leqslant 25$ MeV are taken from miscellaneous sources such as NDA-2111-3, BNL-325, an output tape from ORNL's O5R program, etc.

5. Shielding Materials and Configurations

5.1 Materials. Soil and ordinary concrete were considered as a mixture of Al, O, and H. Heavy concrete as a mixture of Fe, O and H. Table 1 gives some relevant parameters.

Table 1

Material	Water *	Density
Compacted Soil	15%	1.8 g/cm^3 = 112 lb/cu. ft.
Ordinary Concrete	6.5%	2.3 g/cm^3 = 144 lb/cu. ft.
Heavy Concrete	7%	4.0 g/cm^3 = 250 lb/cu. ft.

* Percentage by weight calculated as follows,

100 (wet - dry)/wet.

5.2 Configurations

Roof = 1 ft ordinary concrete + soil

Wall (1) = solid ordinary concrete

Wall (2) = 2 slabs 1 ft. thick each of ordinary concrete + compacted soil.

Wall (3) = solid heavy concrete, using a removal mean free path (117/112) longer than that for ordinary concrete.

6. Results

6.1 Form. The results of interest in a biological shield are given in dose equivalent as a function of geometey and source strength. Thus,

$$D(R,X) = K R^{-1} \exp(-X/L) \text{ Rem/hr}$$

for 3.76 x 10^8 protrons sec^{-1} cm^{-1} of energy E_p, on copper. K and L are given in Table II.

Table II

E_p MeV	K_{soil} Rem. cm. hr^{-1}	L_{soil} g/cm^2	K ord concr. Rem. cm. hr^{-1}	L ord concr. g/cm^2
25	59.052	25.560	210.87	26.914
50	125.16	39.230	211.29	40.593
100	295.19	59.492	378.39	60.877
150	510.55	71.368	658.292	77.845
200	990.38	85.129	1214.02	85.802

The predicted doses should be believable within a factor of 2 to 3!

The five digits given in Table II come from a least square fit to the results calculated by K. O'Brien.

6.2 Applications to specific situations. Curves.

All curves, unless otherwise indicated, are for $(di/dL) = 3.76 \times 10^8$ p cm^{-1} sec^{-1}.

6.2.1. Roof requirements.

Linac center line is @ 740 feet

Roof bottom is @749 feet

Roof to center line = 9 feet

Unrestricted Occupation Area = $.8 \times 10^{-4}$ rem/hr. Minimum uniform soil fill on top of linac = 14 ft, provided that the high water content shown in the deep soil samples (18%) is maintained at all times.

6.2.2 Lateral Shield

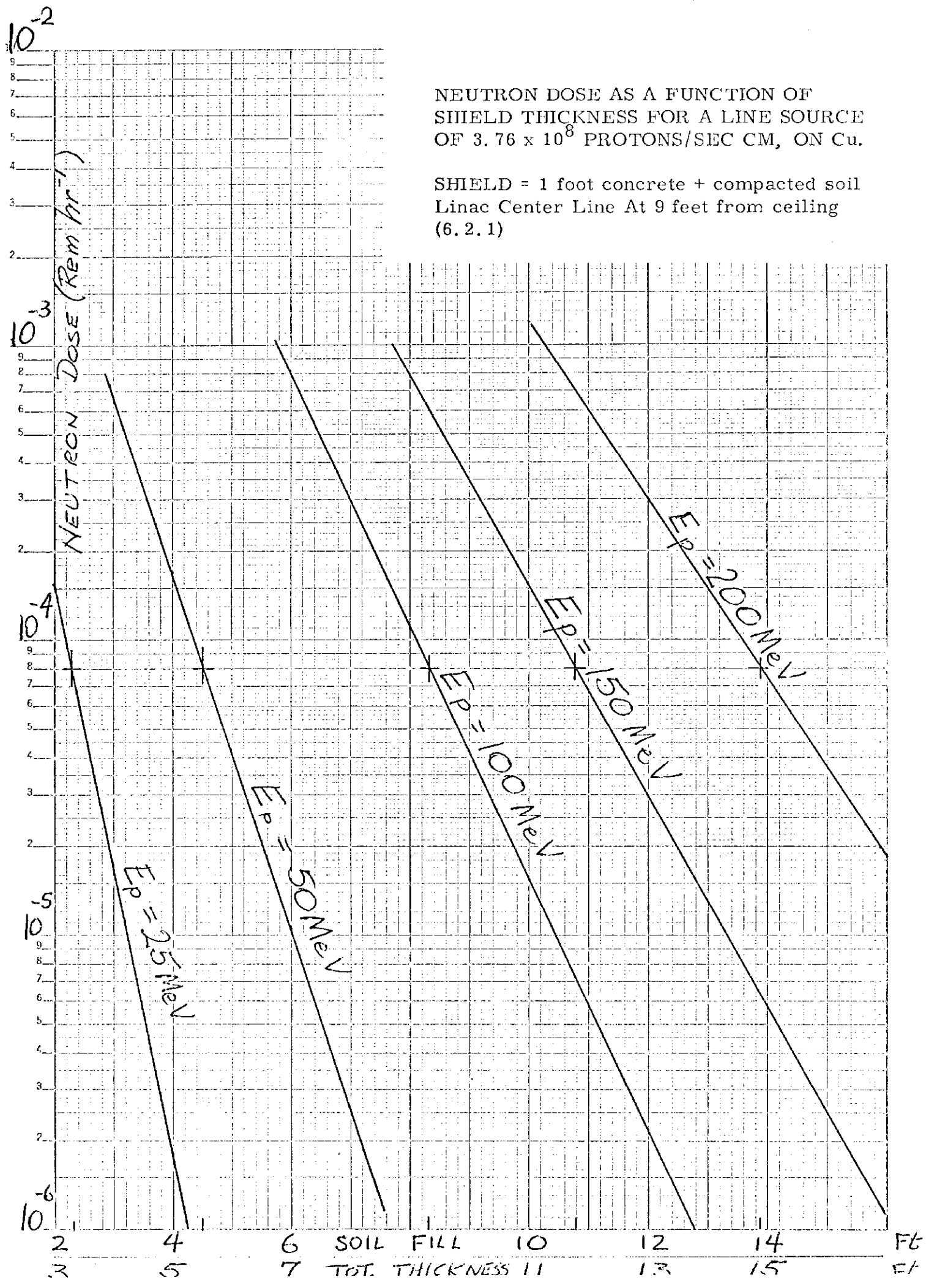
Linac center line is @ 6 ft from wall. Solid ordinary concrete wall.

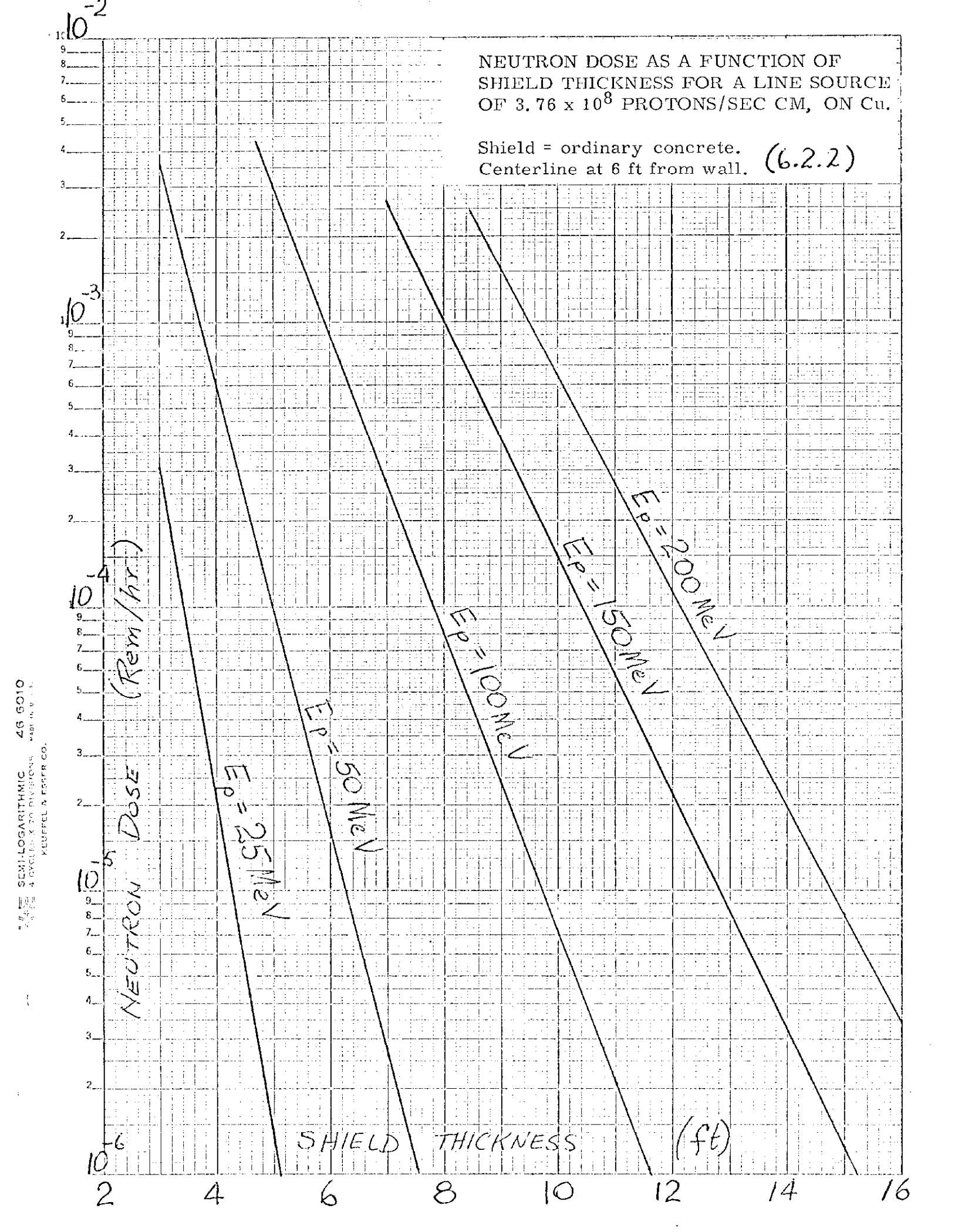
6.2.3. Lateral Shield

Linac center line is @ 6 ft from wall. Two slabs 1 ft. thick of ordinary concrete + compacted soil (18% water content).

6.2.4 Lateral Shield

Required minimum thickness for the linac at 6 ft from wall for a dose of 0.8×10^{-4} rem/hr, as a function of energy.

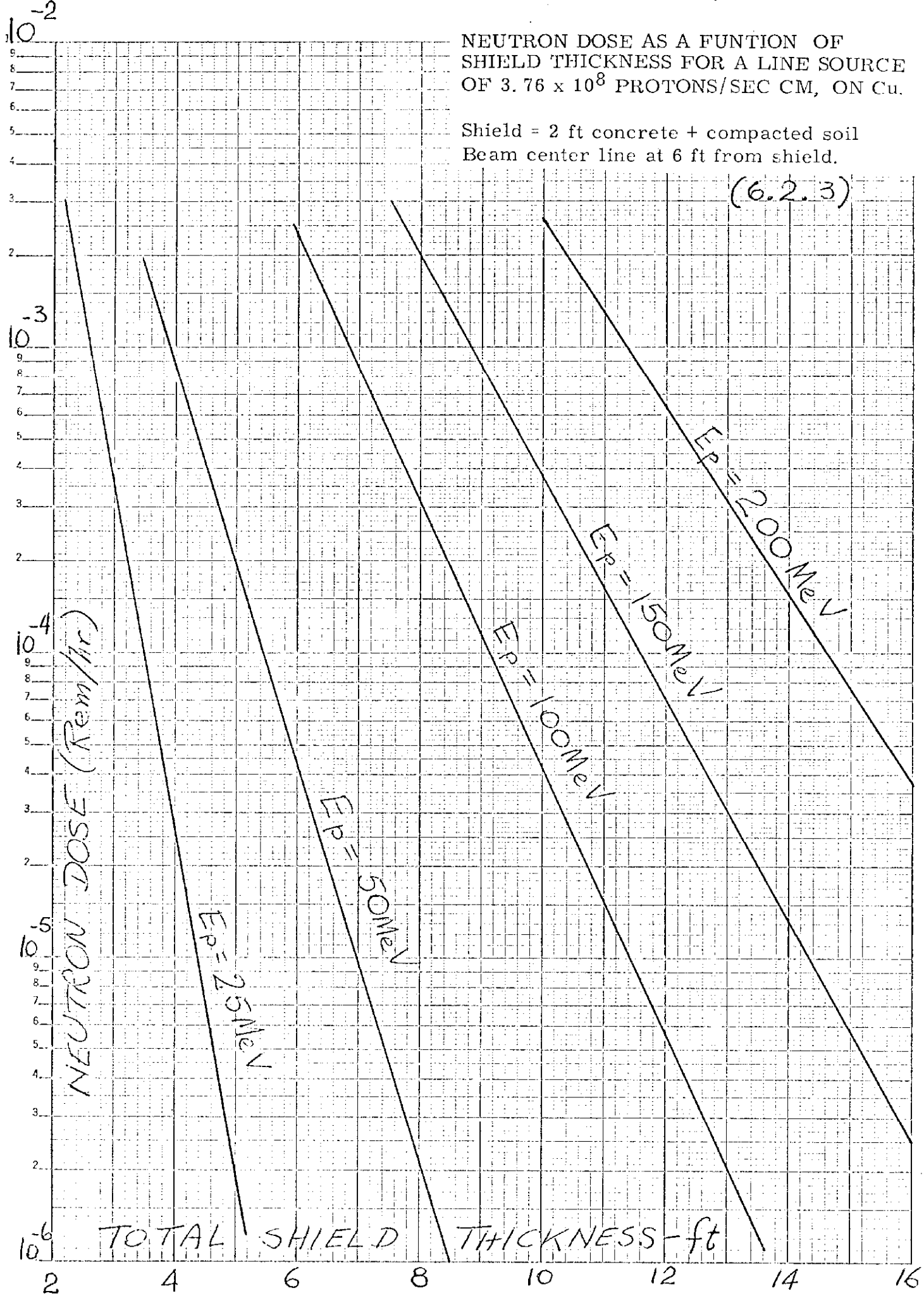

NEUTRON DOSE AS A FUNCTION OF SHIELD THICKNESS FOR A LINE SOURCE OF 3.76 x 10^8 PROTONS/SEC CM, ON Cu.
SHIELD = 1 foot concrete + compacted soil
Linac Center Line At 9 feet from ceiling
(6.2.1)
NEUTRON Dose (Rem hr^-1)
10^-2
10^-3
10^-4
10^-5
10^-6
Ep = 25 MeV
Ep = 50 MeV
Ep = 100 MeV
Ep = 150 MeV
Ep = 200 MeV
2
4
6
SOIL FILL
10
12
14
Ft
3
5
7
TOT. THICKNESS 11
13
15
Ft
SEMI-LOGARITHMIC
45 6010


NEUTRON DOSE AS A FUNCTION OF SHIELD THICKNESS FOR A LINE SOURCE OF 3.76 x 10^8 PROTONS/SEC CM, ON Cu.
Shield = ordinary concrete.
Centerline at 6 ft from wall.
(6.2.2)
NEUTRON DOSE (Rem/hr.)
SHIELD THICKNESS (ft)
Ep = 25 MeV
Ep = 50 MeV
Ep = 100 MeV
Ep = 150 MeV
Ep = 200 MeV
10^-2
10^-3
10^-4
10^-5
10^-6
2
4
6
8
10
12
14
16

NEUTRON DOSE AS A FUNTION OF SHIELD THICKNESS FOR A LINE SOURCE OF 3.76×10^8 PROTONS/SEC CM, ON Cu.

Shield = 2 ft concrete + compacted soil
Beam center line at 6 ft from shield.

(6.2.3)



SHIELD THICKNESS REQUIRED FOR A DOSE EQUIVALENT RATE OF 0.8×10^{-4} REM HR^{-1} FOR A LINE SOURCE OF PROTONS ON Cu.
SOURCE STRENGTH = 3.76×10^{8} protons sec^{-1} per cm.
LINE SOURCE AT 6 FT FROM SHIELD.

Shield A: 2 concrete walls, 1ft thick each + + compacted soil.
Shield B: solid concrete.

Concrete: density 2.3 g/cm^3
Soil compacted to 1.8 g/cm^3 water content 15%

(6.2.4)